THE ROLE OF AUGMENTED REALITY ON SPATIO-TEMPORAL DECISION MAKING IN THE CONTEXT OF INDOOR NAVIGATION

A Thesis

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Master of Science in Human Environment Relations

by

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ABSTRACT

This study is an empirical study that explores the effect of an Augmented Reality (AR)-enabled navigation aid on indoor navigation performance and user experience. A new AR-enabled navigation aid prototype was developed for this study. Its user ratings and navigation performance records were compared to those of a printed map. A total of 50 college students participated in the study, and each participant experienced two conditions with different navigation routes presented in a randomized order. During each condition, participant performed a navigation task with a destination and a route recall task to retrace the navigation path without any navigation aid. The results showed that in terms of navigation task, participants required shorter navigation time and made fewer errors with an AR-enabled navigation aid than with a printed map. The results of route recall task demonstrated a significant effect of participants' culture. In the printed map condition, East Asians required shorter route recall time and made fewer errors than European Americans. In the AR-enabled navigation aid condition, European Americans required shorter route recall time and made fewer errors than East Asians. Findings from the current study highlight new factors such as individual differences shaped by culture in affecting a person's navigation behavior. Such findings will be beneficial to researchers and app developers interested in successfully merging AR technologies with current indoor navigation aids.

BIOGRAPHICAL SKETCH

Seo Hyon Lee was born and raised in Seoul, Korea. She completed the Bachelor of Science program at Cornell University's Department of Design and Environmental Analysis in 2016, and is currently pursuing the Master of Science program in the same department with a concentration in Human Factors and Ergonomics.

Dedicated to my parents

Byung Ik Lee and Eun Soon Im,

and my great brother Seung Gi Lee

for their endless support and love

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CHAPTER 1

INTRODUCTION

Although wayfinding is an essential part of our everyday life, doing so inside an unfamiliar and complex building can be onerous for many people. It poses significant technical and human performance challenges, particularly in time-sensitive or mission-critical contexts. There are many factors, both internal and external, that affect a person's wayfinding ability (Garling et al., 1986). External factors refer to environmental characteristics such as complexity of building layout and availability of landmarks. Internal factors refer to individual differences in familiarity of the environment and types of wayfinding strategies (Prestopnik & Roskos-Ewoldsen, 2000). Past research attempted to understand individual's wayfinding strategies through studying spatial cognition. However, only few studies explored the relationship between individual differences in cognitive processing styles and wayfinding behaviors. Depending on how people view and process spatial information, preferences for visuospatial input and displays of wayfinding aids may vary.

One of the most popular wayfinding aids is a two-dimensional (2D) representation of a space, such as a printed map. The 2D representation captures a holistic view of the environment and is typically displayed on a paper or a digital screen. However, with the advent of Augmented Reality (AR) technologies and its' ability to integrate 3D directional cues overylaying the physical environment, app developers and researchers are increasingly turning to AR as a new wayfinding aid that can replace 2D maps. Unfortunately, since AR is a relatively new technology, little research has examined the impact of AR on spatio-temporal wayfinding decision making and how it influences spatial knowledge acquisition. This study aims to understand how AR applications help nurture the spatial learning process and improve one's spatial memory through a new AR-enabled navigation aid.

In this section, wayfinding and navigation will be defined. Then, literature on spatial knowledge acquisition, individual differences in spatial ability, and the history and advancement of AR technology will be reviewed and discussed.

1.1 Definition

Wayfinding versus Navigation

The terms, wayfinding and navigation, are often used interchangeably because both involve similar behavioral and cognitive processes. Nonetheless, it is necessary to acknowledge important distinctions among these processes.

According to researchers in human factors and ergonomics (HF/E)(Taylor et al., 2008), wayfinding is a behavior of finding one's way from an origin to a destination based on existing knowledge. By gathering information from prior experience, people form abstracted and comprehensive mental models of an environment. More specifically, wayfinding requires both the performance to find a way (wayfinding performance) and the orientation behavior in a new environment (exploration behavior) (Jansen-Osmann, Schmid, & Heil, 2007). Solving complex wayfinding tasks require individuals' thought processes and perceptions about how things work, i.e., mental models. The cognitive mechanism derives information from the dynamics between acquired spatial knowledge and positioning within an environment.

On the other hand, navigation is a behavior of following a prescribed series of turns and distances. Unlike wayfinding, navigation does not require mental processes of spatial representations; in other words, navigation is as simple as route following.

Although navigation is a simple process, designing for useful navigation aid is exceedingly complex (Brunye et al., 2007; Wickens et al., 2005). Such challenges are related to several fundamental issues: dynamic user tasks and goals, varying previous experience and spatial memory, and various types of complex environments within which users operate (Taylor et al., 2008). Thus, this study aims to explore the potential benefits of AR-enabled navigation aid in light of these challenges.

1.2 Spatial Knowledge Acquisition

Cognition & Perception

Wayfinding studies often use cognitive maps and spatial perception as measures of wayfinding performance. According to Gifford (2014), from the perspective of environmental psychology, it is important to make distinctions between environmental *perception* and environmental *cognition*. While environmental psychologists often treat “perception” and “cognition” as different phenomena, some psychologists, urban planners, and social theorists challenge this bifurcation.

By definition (Gifford, 2014), environmental *perception* describes the initial gathering of information by which a person collects information through all his senses. This means what people see, hear, and feel shapes their understanding of the environment. Environmental *cognition*, on the other hand, describes how we think about places; more specifically, it is concerned with how people acquire, store, organize, and recall information about locations, distances, and arrangements of landmarks. In short, environmental cognition is closely related to personal memories and experiences from the past.

Wayfinding depends on individual abilities and environmental characteristics. It is difficult to conclude whether one’s spatial ability—the capacity to understand and remember spatial relations among objects or space (Lohman, 1988)—is determined by pre-existing knowledge (Milgram & Jodelet, 1970) or by new information gathered through the environment (Lynch, 1960). Therefore, due to the uncertainty of concluding factors of spatial ability, this study requires sound scales measuring cognitive processes of perceiving and restoring spatial information.

Environmental Knowledge

Several empirical studies have found that individual navigation performance differs by the types of navigation strategy used (Berry & Bell, 2014). The two main strategies are landmark-based route strategy and pointing-based survey strategy (Montello & Sas, 2006).

The landmark-based route strategy pertains to the connections between landmarks and the knowledge required to go from one landmark to the next. The pointing-based survey strategy requires a compilation of previously learned knowledge and the intervening perception of spaces. These information are used to make a mental representation of a space including distance and directional relationships among landmarks. A deeper understanding of differences in navigation strategies allows us to predict natural human behaviors and helps policy-makers and planners to better reflect the needs of their target user group.

1.3 Individual Differences

Spatial Ability

The focus of this study is to examine the individual differences and understand why some are better at wayfinding than others. One interesting study regarding navigational ability examines a navigation-related structural change in the hippocampi of London taxi drivers (Maguire et al., 2000). This study analyzes the structural MRIs of human brains with extensive navigation experience by comparing licensed London taxi drivers to a control group of subjects who do not drive taxis. The results show that increased hippocampal volume leads to better spatial awareness and spatial memory for navigation. In effect, an experienced taxi driver can perform a phenomenal wayfinding without navigational aids, presumably drawing from their extensive experience-based spatial mental model. Chase (1983) also supports the idea that experienced taxi drivers can generate novel routes and remember street names better than regular pedestrians or bus drivers. These findings support the meaningful associations between individuals' experience, perspectives, and visuospatial abilities with their navigation strategies for wayfinding.

Cognitive Processing Styles & Culture

Research in cognitive psychology often study culture and ethnicity from various points of view. One point of view is to study culture and ethnicities' effect on visual perception and cognitive processing styles. Chua et al. (2005) found the different viewing patterns among East Asians and European Americans through studying their eye movements. The two cultural groups were shown photographs of a naturalistic scene with a focal object on a complex background. The results indicated that European Americans tend to recognize the focal objects quicker and attend more to the focal objects than do East Asians. East Asians, on the other hand, tend to spend more time looking at the background than do European Americans. Some researchers argue that cultural differences in eye movements could stem from several sources such as expertise, socialization, or differences in experience.

Masuda and Nisbett (2006) also support these findings through the change-blindness paradigm. In their study, American and Japanese participants were shown two animated vignettes of a scenery with differences in attributes of focal objects as well as in background field or objects. Consistent with the previous research findings, American participants responded more to focal objects, whereas Japanese participants responded more to background and relationship between the objects.

There are other differences among various cultural groups. Another study by Chua et al. (2005) demonstrated that perception and memory of social behaviors in everyday life also depend on culture. When presented with a written narrative of social events occurring to several characters in a plot, American participants were better able to recall the actions and events related to the main character than Taiwanese participants. On the other hand, Taiwanese participants were better able to recall a general story line and the relationship between the characters.

As supported by aforementioned research, differences in culture leads to differences in cognitive processing styles and visual perception. Therefore, navigation, which involves both cognitive processing and visual perception, could also be affected by differences in culture.

Visual Cognitive Processing Styles

Aside from cultural factors, individual difference in visual cognitive processing styles can also affect navigation performance. There are several studies that examine how each individual sees things and processes information differently. Some researchers (Blajenkova et al, 2006) explained that there are two types of visualizers: object imagers versus spatial imagers. Another researcher (Abu-Obeid, 1998) tried to understand the different types of visual cognitive processing styles in relation to understanding the environmental layout. In effect, he named the two types of visual imagery as abstract imagery versus scenographic imagery.

According to Blajenkova, Kozhevnikov, and Motes (2006), object imagers tend to process visual information in term of form, size, shape, color, and brightness of objects. In contrary, spatial imagers tend to use relatively abstract representation of the spatial relations among objects. In other words, spatial imagers tend to pay more attention to the locations of objects in space or the movement of objects relating to the spatial transformations than object imagers. Although this study didn't establish a clear correlation between wayfinding behaviors and visual cognitive processing styles, its findings nonetheless show significant relevance between the two. The researchers found that object imagers performed significantly better on object imagery tasks (i.e. Degraded Pictures test) than spatial imagers. Spatial imagers, on the other hand, scored much higher in spatial imagery tasks (i.e. Wire Frame problem, Figure Rotation and Combination problem, and Folded Box problem from the Imagery Testing Battery) than object imagers.

Abu-Obeid (1998) defined the two types of visual imagery as abstract imagery and scenographic imagery in relation to the environmental layout. Unlike Blajenkova et al. (2006), he focused on the connection between visual imagery and wayfinding behaviors in more detail. He claimed that abstract imagery represents a form of map-like information which is primarily linked to the mental representation of the spatial layout or topological geometric system. On the contrary, scenographic imagery refers to the pictorial information perceived through sensory experience such as buildings' contours, shapes, surface qualities, entrances, etc. This study shows that an individual tends to develop a stronger sense of one or the other, thus resulting in different wayfinding behaviors of an individual or a cohort group.

Although the aformentioned studies did not directly measure visual processing styles in relation to one's wayfinding behaviors, it seems highly probable that differences in visual cognitive processing styles may have an influence on shaping one's spatial ability and individual navigation strategy. Therefore, differences in visual cognitive processing styles should be given more light in terms of wayfinding studies.

1.4 Augmented Reality

Augmented Reality (AR) is a fast-growing technology that enhances our perception and experience of the world in new and enriched ways (van Krevelen & Poelman, 2010). Augmented Reality uses virtual or computer-generated objects that are superimposed onto the real environment. The virtual objects run interactively in real time, and combine real and virtual objects in a physical environment. In effect, AR enables us to experience both reality and virtuality simultaneously. AR has been studied and developed for decades, but the field of AR took longer to advance than that of Virtual Reality (VR) because of the higher technological demands for AR.

The first AR prototype was introduced in the 1960s by Ivan Sutherland and his students at Harvard University and the University of Utah (van Krevelen & Poelman, 2010). Sutherland's prototype, "the Sword of Damocles," employed an optical see-through that presented 3D graphics. Transparent mirrors displayed an AR overlay without disturbing real-world perceptions (van Krevelen & Poelman, 2010). However, it wasn't until the 1990s that AR became an actual field of study. In 1992, Caudell and Mizell first coined the term 'augmented reality,' and AR has since then been evolving. Unlike VR technology which requires head-mounted displays or screen displays to block the real-world view, AR technology allows users to simultaneously interact with both virtual and real-world views. The mobile industry has perhaps seen the greatest advancement in AR use. In 1997, a small group of engineers and architects created a prototype of a mobile AR system (Feiner et al., 1997). Their system overlaid 3D graphical tour guide information onto surrounding buildings and artifacts for the visitors to see.

However, technical challenges remain. Although AR technology such as The Mobile AR System (MARS) can reduce spatial limitation challenges that traditional VR technology imposes, AR still faces hardships in terms of tracking user position and orientation. In order to track user position, the AR system needs to measure the user's movement with six degrees of freedom (6DOF) involving three positional variables (x, y, z) and three orientational variables (pitch, yaw, and roll) (van Krevelen & Poelman, 2010). Even leading technological companies such as Google, Apple, and Samsung are yet to successfully register all six movements via mobile device.

In terms of visual display, AR has three ways of presenting virtual objects that are superimposed onto the real world. First is 'video see-through' which means that instead of using computer-mediated environment (as in VR), the augmented objects are overlaid onto the pre-recorded videos of reality (Liu et al., 2009). The second is 'optical see-through' which is a technique that requires either a head-worn display, hand-held display, or a spatial setup where the AR overlay can be reflected from the transparent mirrors and lenses (van Krevelen & Poelman, 2010). This approach is known as the safest method because it carries the real-world view behind the augmented elements. So even if the overlaid AR displays fail, there will be less safety issues because users can still see the real-world surroundings. The final approach is 'projective.' This projects an AR overlay onto real objects using projectors or some sort of light simulators. Its greatest benefit is that it does not require special eye-wear or hand-held devices, and it can be projected on large surfaces supporting a wide-angle view (Zhou et al., 2008). In recent years, we have coined this approach Projection Mapping.

The unique possibilities of AR technology were explored in our study. The AR-enabled navigation aid was developed using the optical see-through technique since similar products weren't available in the market. A series of virtual signage was created using Unity 3D. The digital signage was then superimposed onto the testing environment through a Google Tango phone.

CHAPTER 2

RESEARCH METHODS

2.1 Research Questions

The focus of this study is to understand how AR plays a role in performing navigation. The study attempts to examine the effect of AR-enabled navigation aid on navigation performance and user experience in comparison with a printed map. In understanding the relationship, culture and individual differences in cognitive processing styles are considered as moderating factors. Supported by the aforementioned literature, there are two types of viewing patterns: object imagery which focuses on detailed view and spatial imagery which focuses on holistic view of a space. Thus, the current study uses an AR-enabled navigation aid to provide more object-focus visual cues and a printed map to provide more holistic information of a space. This study is also interested in how these different types of navigation aids affect user experience of individuals with different cultural backgrounds and cognitive processing styles. Specifically, this research seeks empirical answers to the following research questions:

1. If and how an AR-enabled navigation aid affect navigation and spatial memory in comparison with a printed map?
2. If and how cross-cultural differences known in cultural psychology play a role in the user experience with AR-enabled navigation aids in comparison with a printed map?

Hypotheses are formulated to answer these research questions as discussed in the following section.

2.2 Hypotheses Development

Two research frameworks are developed to examine the hypotheses (Figure 1&2). The first framework (Figure 1) predicts that there will be an effect of navigation aid type on navigation performance moderated by culture. In our study, we define "navigation performance" as an over-arching term for describing the navigation time, navigation error, route recall time, and route recall error.

The following hypotheses guided the first research framework:

Hypothesis 1. The navigation aid type will have an effect on navigation performance.

H 1-1. The navigation time of all participants will be shorter when using an AR-enabled navigation aid than using a printed map.
H 1-2. The navigation error of all participants will be fewer when using an AR-enabled navigation aid than using a printed map.
H 1-3. The route recall time of all participants will be shorter when after using a printed map than an AR-enabled navigation aid.
H 1-4. The route recall error of all participants will be fewer when after using a printed map than an AR-navigation aid.

Hypothesis 2. The effect of navigation aid type on navigation performance will be moderated by culture.

H 2-1. There will be an interaction effect between navigation aid type and culture on navigation time.
H 2-2. There will be an interaction effect between navigation aid type and culture on navigation error.
H 2-3. There will be an interaction effect between navigation aid type and culture on route recall time.
H 2-4. There will be an interaction effect between navigation aid type and culture on route recall error.

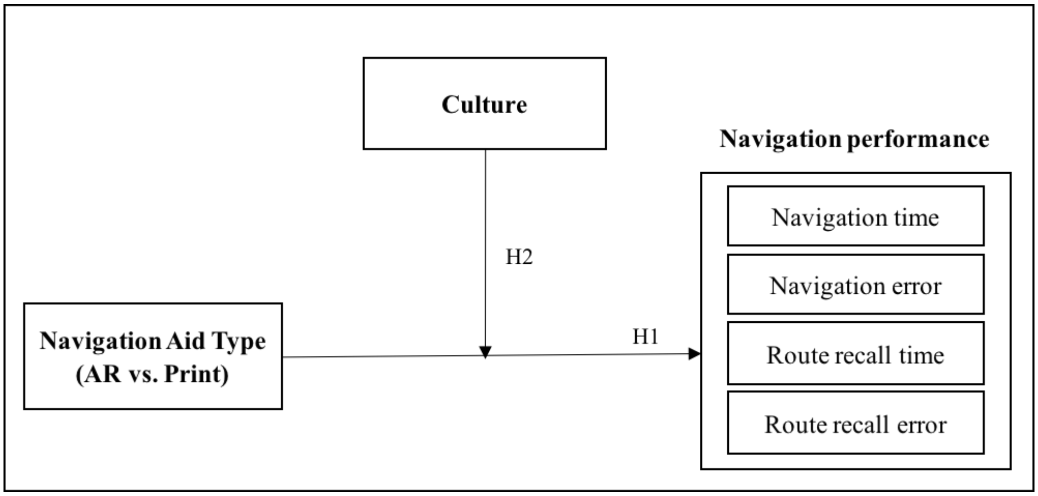

Figure 1. Research Framework 1

The second research framework (Figure 2) was developed to predict the effect of individual differences in cognitive styles on perceived helpfulness and user experience and to investigate a moderating effect of the navigation aid type. The perceived helpfulness on navigation performance is measured after using each map type during navigation and route recall tasks. User experience is operationalized by attractiveness, novelty, efficiency, perspicuity, stimulation, and dependency.

The following hypotheses guided the second research framework:

Hypothesis 3. The navigation aid type will moderate the effect of individuals' cognitive processing styles on perceived helpfulness in navigation performance.

Navigation Task

H 3-1. As global thinking tendency increases, a printed map will be perceived more helpful in navigation task than an AR-enabled navigation aid.

H 3-2. As AHS score increases, an AR-enabled navigation aid will be perceived less helpful in navigation task than a printed map.

H 3-3. As spatial imagery tendency increases, an AR-enabled navigation aid will be perceived less helpful in navigation task than a printed map.

H 3-4. As object imagery tendency increases, an AR-enabled navigation aid will be perceived more helpful in navigation task than a printed map.

Route Recall Task

H 3-5. As global thinking tendency increases, a printed map will be perceived more helpful in route recall task than an AR-enabled navigation aid.
H 3-6. As AHS score increases, an AR-enabled navigation aid will be perceived less helpful in route recall task than a printed map.
H 3-7. As spatial imagery tendency increases, an AR-enabled navigation aid will be perceived less helpful in route recall task than a printed map.
H 3-8. As object imagery tendency increases, an AR-enabled navigation aid will be perceived more helpful in route recall task than a printed map.

Hypothesis 4. The navigation aid type will moderate the effect of individuals' cognitive processing styles on user experience.

H 4-1. As global thinking tendency increases, users will perceive higher efficiency when using a printed map than using an AR-enabled navigation aid.
H 4-2. As AHS score increases, users will perceive higher novelty when using an AR-enabled navigation aid than using a printed map.
H 4-3. As spatial tendency increases, users will perceive higher perspicuity when using a printed map than using an AR-enabled navigation aid.
H 4-4. As object tendency increases, users will perceive higher attractiveness when using an AR-enabled navigation aid than using a printed map.

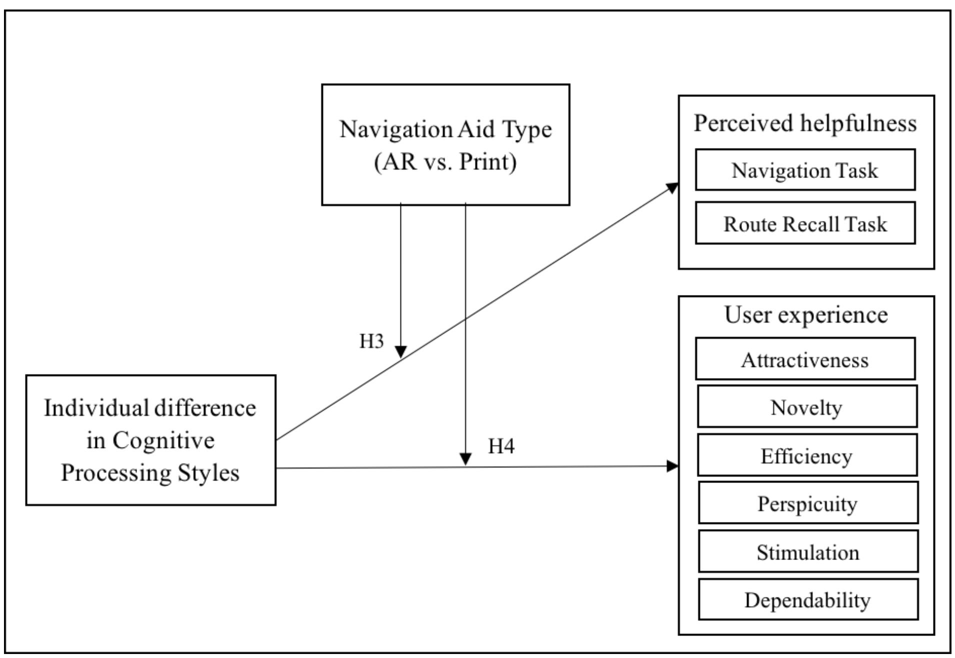

Figure 2. Research Framework 2

2.3 Study Design

This study was a true experiment, using within-subjects design, which compared individual's navigation performance between two navigation types (AR vs. printed map). The first condition was navigating with the AR-enabled navigation aid. When holding AR-enabled navigation aid, object-based cues were displayed on the mobile screen (Google Tango Phone) as participants pass by a certain location or landmark. Simultaneously, a virtual directional arrow was superimposed onto the floor, showing how to get to the destination (Figure 3). The second condition was navigating with printed map with pre-determined routes (Figure 4). Each subject was exposed to both conditions in randomized orders.

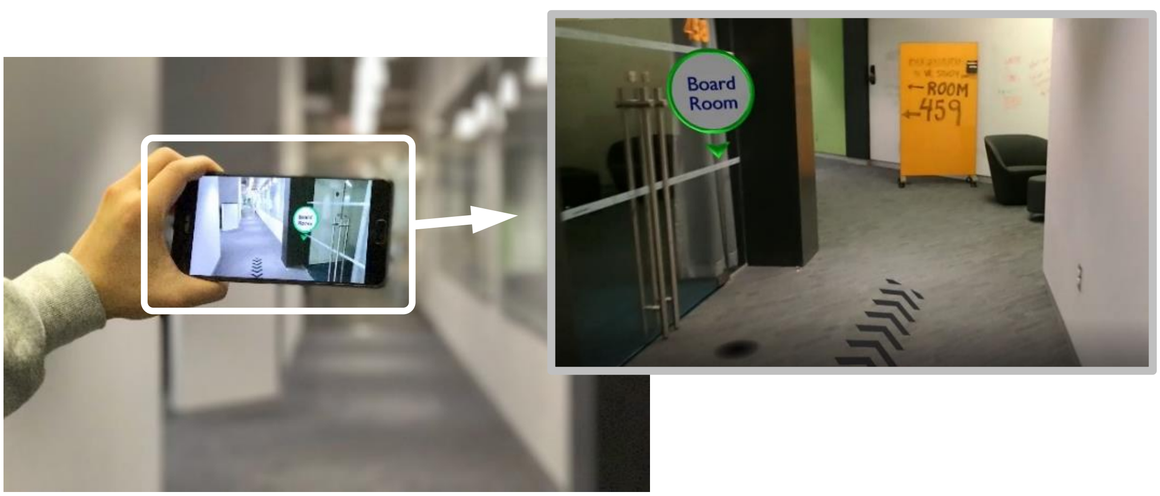

Figure 3. Display of AR-enabled navigation aid and detailed navigation aid shown on a mobile screen

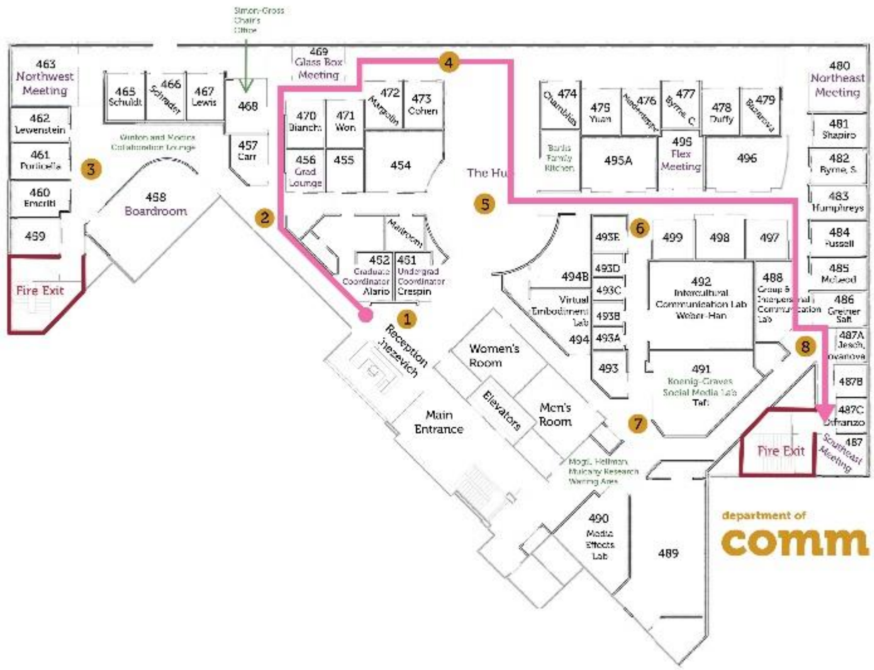

Figure 4. Printed map with pre-determined routes

2.4 Participants

Fifty university students (9 men, 41 women) from Cornell University were recruited via convenience sampling for participation in the study. The sample includes various ethnicities: 29% East Asians (*N*=15), 22% Asian Americans (*N*=11), 6% African Americans (*N*=3), 8% Hispanic or Latino (*N*=3), and 35% European Americans (Origins in Europe, the Middle East, or North America) (*N*=18). Ages of the participants range from 18 through 40 years old.

2.5 Procedures

The study was conducted in the fourth floor of Mann Library at Cornell University. In order to reduce a chance of learning about the testing space before experiments, participants were asked to meet the investigator in front of the main entrance. The investigator guided them to a side entrance where it did not introduce routes that were used during the experiment. First, participants were seated in a quiet lounge and signed the consent form. After signing the consent form, participants were asked to complete a pre-task questionnaire.

The pre-task questionnaire asked 6 questions prior to the experiment. Those questions included general demographic information (4 items) and dependency on navigation aid (2 items) (See Appendix B).

After completion of the pre-task questionnaire, participants were randomly given one navigation aid (either a printed map or an AR-enabled navigation aid). Each navigation aid was provided with a pre-determined route. It was important to determine a specific route in advance to maintain the same distance traveled and the number of intersections. The pre-determined routes were indicated both on the printed map and AR-enabled navigation aid, shown in Figure 4. During each condition, the task was to find a fire exit on the fourth floor of Mann Library. When participants successfully reached the destination, they were asked to retrace the same route they had traveled without the provided map.

Immediately after each task, participants were asked to complete a post-task questionnaire. The post-task questionnaire after Condition 1 included Task Confusion & Clarity of hallway layout (6 items) and Semantic Differential for User Experience Questionnaire (20 items). After Condition 2, the same post-task questionnaire was distributed with an additional section asking how helpful was each navigation aid type when doing the navigation and route recall tasks. The perceived helpfulness in the navigation and route recall tasks was compared between the AR-enabled navigation aid and the printed map. The post-task questionnaires are presented in Appendix C.

After a week, participants were asked to complete a survey regarding individual cognitive processing styles. This survey was distributed after the experiment because the questions may influence their performance and some might be able to guess what this study was trying to measure. The survey included four scales: Indoor navigation strategy (6 items), Object-spatial imagery questionnaire (16 items), Analysis-Holism Scale (24 items), and MSG Thinking Style Inventory – specifically focusing on global (8 items) and local (8 items) thinking styles. The list of the survey is shown in Appendix D.

2.6 Experimental Settings

The navigation and route recall tasks took place in the Department of Communication at Cornell University. It is an office floor that maintains various office rooms, labs, open collaboration space, kitchen, and a supply room. This space was appropriate for this navigation study because visitors and even the frequent occupants of this floor often reported complaints about its complexity of layout. This space was also in lack of distinctive visual cues because almost all rooms have identical exterior with glass doors. After conducting a few pilot studies, two different routes for each type of navigation were determined (Figure 5). As briefly mentioned early, it was imperative to present pre-determined routes on both navigation aids because there is a chance that some participants may take a shorter or easier route than others. The inconsistency of routes taken by a participant may result in inaccurate route recall ability of the sample. Also, since AR-navigation aid was our self-developed prototype with no GPS signal, it could only present a pre-recorded route. It would not redirect a subject if he or she gets off the suggested route. Lastly, in order to control the level of difficulty, both routes maintained the same number of intersections (7) and similar distance travel (approximately 1 min 30 sec at a normal walking speed).

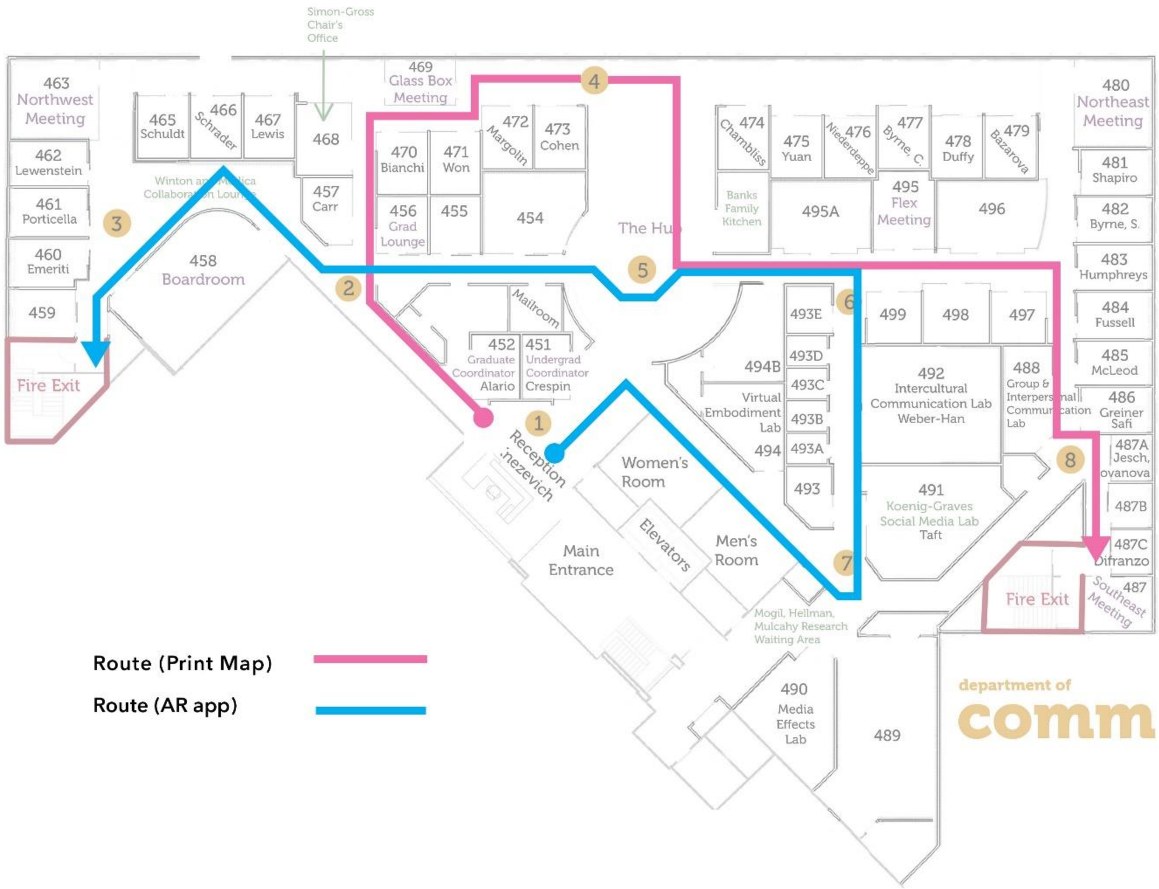

Figure 5. Travel Routes indicated on the floor plan of the experimental space

2.7 Measurement

Below scales are the constructs of Individual differences in cognitive processing styles.

***Individual Navigation Strategy*.** This scale consists of six items that measured individual navigation strategy. The navigation was measured using average responses of route and survey strategy scales designed and validated by Berry and Bell (2014). Using a five point Likert type scale, participants were asked to rate how much they agree on a series of statements. The questions included such as “I always keep in mind which direction I am moving (e.g. north, south, east, or west).” “It takes me a lot of mental effort to figure out my facing direction." "Labeled room numbers identifying parts of the building are very helpful in finding my way." A complete list of this scale is shown in Appendix D.

Object Spatial Imagery Questionnaire (OSIQ). A set of sixteen questions were assessed in the individual characteristics questionnaire to evaluate visual imagery processing styles (object imagery vs. spatial imagery). This scale was used to understand whether an individual is naturally more drawn to object-based cues such as landmarks, size, shapes, color, etc. or more drawn to making a connection between the surroundings and the spatial layout, which help them to make a mental note of their orientation. The Object-Spatial Imagery Questionnaire was directly adopted from a previous study and validated by Blajenkova, Kozhevnikov, and Motes (2006). This study used an abbreviated version of the scale.

MSG Thinking Style Inventory. The original MSG Thinking Styles Inventory (Sternberg & Wagner, 1991) measures 13 different styles of thinking regarding legislative, executive, judicial, global, local, progressive, conservative, hierarchic, monarchic, oligarchic, anarchic, internal, and external thinking styles. For this study, only the global and local sub-scales were adopted from the list. The global style thinker indicates someone who prefers to deal with relatively large issues and likes to think abstract and diffuse ideas. The local style thinker refers to someone who are detail-oriented and likes to deal with problems requiring analytical and detail work. This scale was used to examine whether one cultural group would show a higher tendency towards a certain thinking style than another. Each sub-scale, global and local thinking styles, included 8 items (See Appendix D).

Analysis-Holism Scale (AHS). The Analysis-Holism Scale was used to measure analytic versus holistic thinking tendency between the two cultural groups. This was 24-item scale developed by Choi, Koo, & Choi (2007). The researchers extracted four constructs as the key characteristics of the analytic-holistic style based on the theoretical accounts of other scholars and the empirical evidence by Nisbett and his colleagues (2001): causality, attitude toward contradictions, perception of change, and locus of attention. The first factor – causality – explains interactionism versus dispositionism. Researchers predicted that East Asians focus more on the relationships and interactions between an actor and their surrounding situations than do Westerners. The second factor – attitude toward contradictions – explains how one deals with a situation when two contradictory opposites exist. East Asians, for example, often try to pursue a compromise or middle ground. Westerners, on the other hand, often direct the formal logic approach by choosing one of the two opposite propositions. Third factor – perception of change – indicates one's view of the world. East Asians generally believe that elements are interconnected with one another so that the complex pattern of interactions among the elements results in constant changes among the elements. In contrast, Westerners perceive most objects as independent, which does not dramatically change the essence of an object over time. Lastly, the focus of attention evaluates whether one focuses on the detailed information or the whole picture. By the same logic as other research, East Asians tend to focus attention to the whole rather than a part, whereas Westerners tend to focus on an individual object of specific part. These four factors were measured on a scale of 0 to 7, and the sum of each sub-scale was calculated.

User Experience Questionnaire (UXQ). This scale allowed a fast and immediate measurement of user experience of interactive products (Laugwitz, Held, & Schrepp, 2008) through semantic differential. The use experience questionnaire contained six sub-scales with 20 items in total: attractiveness, efficiency, perspicuity, dependability, stimulation, and novelty. *Attractiveness* indicates general likability towards the product. *Efficiency* measures whether the product is adaptive to use fast and efficiently and also whether the interface look organized. *Perspicuity* indicates the ease of use of the product. *Dependability* measures whether users feel in control of the interaction with the product. *Stimulation* indicated whether the product is interesting and exciting to use. Lastly, *Novelty* indicates if the design of the product is innovative and creative. According to Hassenzahl (2001), *Perspicuity, Efficiency, and Dependability* focus on measuring pragmatic and goal-oriented quality aspects, whereas *Stimulation* and *Novelty* focus on non-goal oriented, hedonic quality aspects. Thus, user experience of each navigation aid type was measured through perceived attractiveness, novelty, efficiency, perspicuity, and stimulation.

Task performance measures. Both navigation and route recall tasks consisted of objective and subjective measures. The object measures included navigation time, navigation error, route recall time, and route recall error. The subjective measures included perceived helpfulness on navigation task and route recall task. The perceived helpfulness of each task was one item questionnaire measured on a scale of 0 to 10. This questionnaire was given after experiencing each navigation aid type.

CHAPTER 3

RESULTS

3.1 Data Screening

Prior to analysis, all variables were examined using SPSS for accuracy of data entry, missing values, and fit between their distributions and the assumptions of multivariate analysis. A total of 50 participants participated in the study. Since participants completed the post-task questionnaire after each condition, task confusion and clarity of layout, perceived helpfulness, and user experience values were recorded twice, totaling 100 cases. However, when discussing the effect of culture on the outcome variables, only three cultural groups (East Asian, Asian American, and European American) were included in the data analysis because the numbers of participants in the Hispanic or Latino group and African American group were too small compared to the other cultural groups. Thus, 88 cases remained for the hypotheses testing. In terms of the individual differences in cognitive styles, 13 out of 50 participants did not complete the online survey, totaling 37 responses. Using SPSS, the data set was scanned for multivariate outliers by looking for values that exceed the Mahalanobis critical value of 20.515 (chi-square, $p < .001$). Multivariate outliers were not detected, and all cases remained for analysis. Characteristics of this sample are presented in Table 3-1.

Table 3-1
Sample characteristics

Demographic Variables		N (50)
Gender	Female	41
	Male	9
Age	Under 21	32
	21~25	16
	Over 25	2

Ethnic Background	Asian	15
	Asian American	11
	African American	3
	Hispanic or Latino	3
	European American (origins in Europe, the Middle East, or North America)	18
	Native Hawaiian or Other Pacific Islander	0

3.2 Measurement Assessment

Reliability refers to the stability of a measure over time and the internal consistency of measures (Nunnally, 1978). The internal consistency of the measurement scales was tested using SPSS to calculate Cronbach's Alpha. Internal consistency reliabilities vary from a low of 0 to high of 1.0. These scores represent the proportion of the variance in the respondents' scores that are attributable to true differences on the psychological construct (DeVellis 1991). DeVellis (1991) recommends an alpha below .60 as unacceptable; .60-.65 undesirable; .65-.70 minimally acceptable; .70-.80 respectable; .80-.90 very good. If much above .90 excellent, the researcher may consider shortening the scale.

To refine the original scales (See Appendix D), item-to-total reliability was examined for each sub-scale. If any individual question reduced the total reliability (Cronbach Alpha) significantly, that item was removed from the scale.

Table 3-2
Reliability test results (N = 37)

Construct	Sub-dimension	Original Number of Items	No. of Items kept	Cronbach's Alpha		
					AR	Print
User Experience Questionnaire	Attractiveness	6	4		.85	.89
	Efficiency	4	3		.74	.88
	Novelty	4	4		.75	.76
	Perspicuity	4	3		.89	.92
	Stimulation	2	2		.29	.57
Navigation Strategy	(N/A)	6	3	.67		
OSIQ*	Object Imagery	8	8	.86		
	Spatial Imagery	8	8	.64		
MSG Thinking Style Inventory	Local Thinking	8	8	.74		
	Global Thinking	8	4	.88		
AHS**	Causality	6	3	.85		
	Att. Contradiction	6	3	.85		
	Perception of Change	6	4	.88		
	Locus of Attention	6	3	.88		

*Object-Spatial Imagery Questionnaire (OSIQ)
**Analysis-Holism Scale (AHS)

Table 3-2 shows the results of reliability tests conducted for all the constructs used in this study. Except for the stimulation and spatial imagery, the values of Cronbach Alpha for each construct exceeded the respectable level of .70 (Cronbach 1951; Nunally 1978). The individual navigation strategy variable was at the minimally acceptable level. Since the scores of the stimulation and spatial imagery were less than .65, these were considered unacceptable. As a result, each subdimension except stimulation and spatial imagery was internally consistent and reliable measures of the associated constructs.

3.3 Hypotheses Testing

To test Hypothesis 1 and 2, a series of ANOVAs of 2 (navigation aid type: AR vs. print) x 3 (culture: East Asian vs. Asian American vs. European American) was conducted on each navigation performance: navigation time, navigation error, route recall time, and route recall error. Although this study was within-subjects design—one participant experiencing both conditions, we coded our data as between-subjects by listing responses of the two conditions separately. The same structure of the coding was used for the remaining analysis. First, the ANOVA results on navigation time showed that there was a main effect of navigation aid type ($F(5,82) = 6.966$, $p = .010$), supporting Hypothesis 1-1. However, the interaction effect between the navigation aid type and culture ($F(5,82) = .056$, $p = .946$) on navigation time was not statistically significant, which did not support Hypothesis 2-1. The main effect of navigation aid type on navigation time indicated that participants in general took more time to complete the navigation task when using a printed map (M = 110.84, sd = 47.78) than using an AR-enabled navigation aid (M = 89.02, sd = 12.20), regardless of culture. Table 3-3 presents the results of ANOVA and Figure 6 shows the mean and standard deviation.

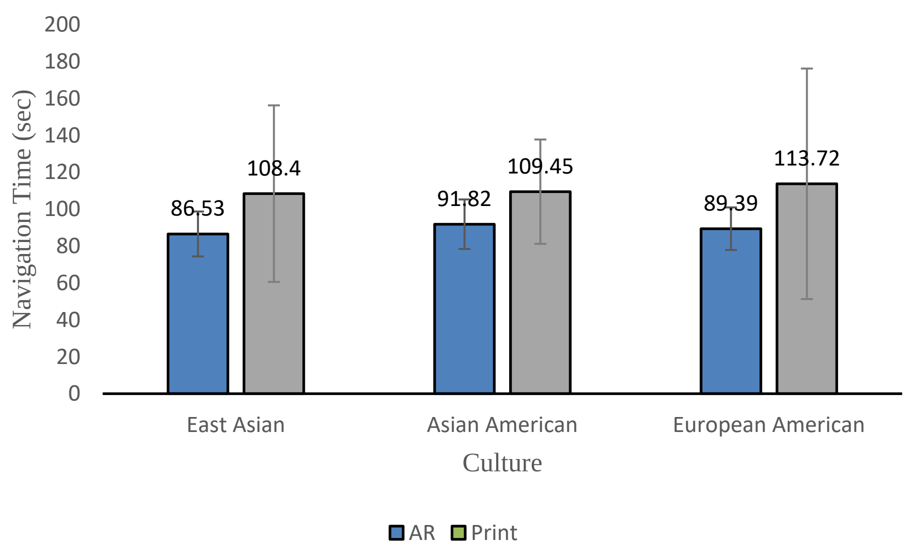

Figure 6. Navigation aid Type and Culture Effect on Navigation Time

Table 3-3
ANOVA Between Subject Effects: Navigation aid type by Culture on Outcome Variables (N=50)

		df	Mean Square	F (1, 82)	Sig.
Navigation Time	Navigation aid Type	1	9560.025	6.966	.010**
	Culture	2	144.072	.105	.900
	Navigation aid * Culture	2	76.567	.056	.946
Navigation Error	Navigation aid Type	1	5.101	7.997	.006**
	Culture	2	.260	.407	.667
	Navigation aid * Culture	2	.260	.407	.667
Route Recall Time	Navigation aid Type	1	3426.758	6.829	.011*
	Culture	2	320.129	.638	.531
	Navigation aid * Culture	2	1750.969	3.489	.035*
Route recall Error	Navigation aid Type	1	7.548	9.306	.003**
	Culture	2	2.072	2.555	.084
	Navigation aid * Culture	2	2.453	3.024	.054*

***p<.001, **p<.01,*p<.05

Table 3-4
Descriptive statistics on the effect of navigation aid type on navigation performance by culture

			N	Mean	Std. Deviation
AR	Navigation Time (sec)	East Asian	15	86.53	12.17
		Asian American	11	91.82	13.43
		European American	18	89.39	11.53
		Total	44	88.86	12.14
	Route Recall Time (sec)	East Asian	15	102.13	23.24
		Asian American	11	93.09	30.89
		European American	18	81.89	13.27
		Total	44	90.54	22.49
	Navigation Error (number)	East Asian	15	0	0
		Asian American	11	0	0
		European American	18	0	0
		Total	44	0	0

	Route Recall Error (number)	East Asian	15	1.33	1.67
		Asian American	11	0.70	1.33
		European American	18	0.28	0.46
		Total	44	0.66	1.21
Print	Navigation Time (sec)	East Asian	15	108.40	47.83
		Asian American	11	109.45	28.27
		European American	18	113.72	62.44
		Total	44	111.86	49.41
	Route Recall Time (sec)	East Asian	15	73.87	10.70
		Asian American	11	82.18	17.12
		European American	18	82.84	31.17
		Total	44	81.18	24.64
	Navigation Error (number)	East Asian	15	0.40	1.30
		Asian American	11	0.73	1.27
		European American	18	0.35	0.86
		Total	44	0.46	1.05
	Route Recall Error (number)	East Asian	15	0.13	0.35
		Asian American	11	0.18	0.41
		European American	18	0.18	0.39
		Total	44	0.16	0.37

Second, the 2 (navigation aid type: AR vs. print) x 3 (culture: East Asian vs. Asian American vs. European American) ANOVA on navigation error showed that that there was a main effect of navigation aid type ($F(5,81) = 7.997$, $p = .006$) with neither the main effect of culture ($F(5,81) = .407$, $p = .667$) no the interaction effect significant ($F(5,81) = .407$, $p = .667$). The main effect of navigation aid type on navigation error indicated that participants committed more errors when using a printed map ($M = .47$, $sd = 1.12$) than using an AR enabled navigation aid ($M = 0$, $sd = 0$), regardless of culture. Overall, hypothesis 1-2 was supported while 2-2 was not supported.

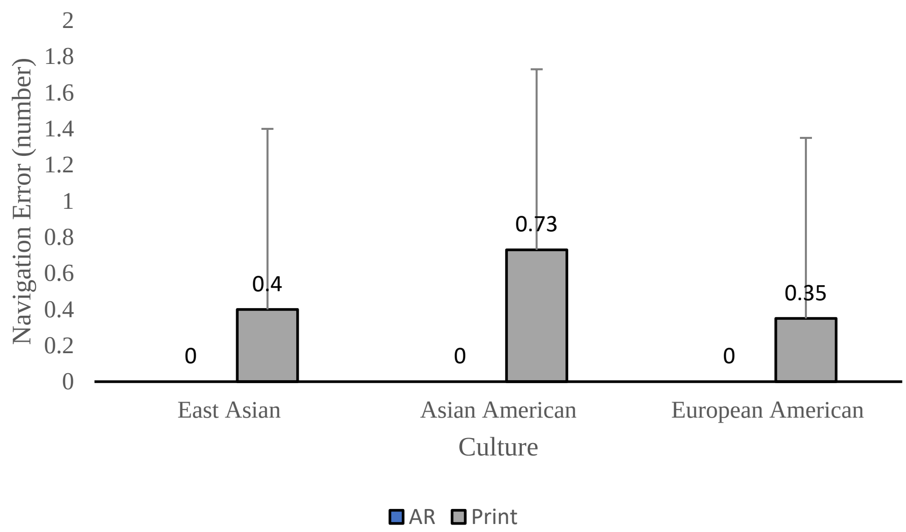

Figure 7. Navigation aid Type and Culture Effect on Navigation Error

Third, the 2 (navigation aid type: AR vs. print) x 3 (culture: East Asian vs. Asian American vs. European American) ANOVA on route recall time was conducted to test hypothesis 1-3 (the main effect of navigation aid type) and hypothesis 2-3 (the interaction effect of navigation aid type and culture). The ANOVA results showed that there was a main effect of navigation aid type ($F(5,82) = 6.829$, $p = .011$) on route recall time, supporting Hypothesis 1-3. Although there was no main effect of culture ($F(5,82) = .638$, $p = .531$), there was an interaction effect of navigation aid type by culture on route recall time ($F(5,82) = 3.489$, $p = .035$), supporting Hypothesis 2-3. The main effect of navigation aid type on route recall time indicated that on average, participants spent more time to complete the route recall task when after using an AR-enabled navigation aid ($M = 91.59$, $sd = 23.37$) than a printed map ($M = 79.62$, $sd = 22.52$), regardless of culture. The interaction effect indicated that the effect of navigation aid type on route recall time was differed by culture. When after using a printed map, East Asians took the least amount of time in completing the route recall task (M

= 73.86, sd = 10.70) when compared with Asian American (M=82.18, sd = 17.12) and European Americans (M = 82.85, sd = 31.17). When after using an AR-enabled navigation aid, however, European American took the least amount of time in completing the route recall task (M = 81.89, sd = 13.27) when compared with East Asian (M = 102.13, sd = 23.24) and Asian American (M = 93.09, sd = 30.89).

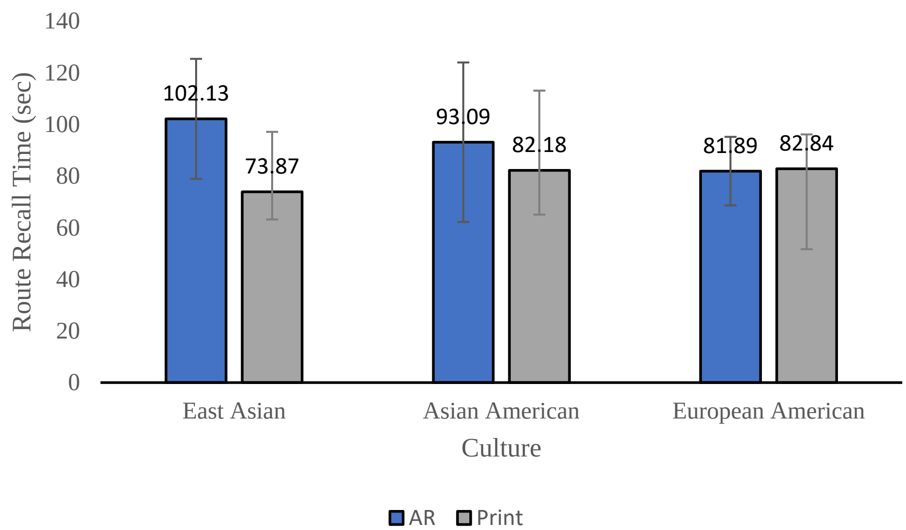

Figure 8. Navigation aid Type and Culture Effect on Route Recall Time

The ANOVA results also showed that there was a main effect of navigation aid type (F(5,82) = 9.31, p = .003) on route recall error, supporting Hypothesis 1-4. Although there was no main effect of culture (F(5,82) = 2.56, p = .084), there was a marginal interaction effect of navigation aid type by culture on route recall error (F(5,82) = 3.02, p= .054), supporting Hypothesis 2-4. The main effect of navigation aid type on route recall error indicated that on average, participants committed more errors to complete the route recall task when after using an AR enabled navigation aid (M = 0.74, sd = 1.27) than a printed map (M =

0.16, sd = 0.37), regardless of culture. The marginal interaction effect indicated that the effect of navigation aid type on route recall error was differed by culture. When after navigated with an AR enabled navigation aid, European Americans committed the least number of route recall errors (M = 0.28, sd = 0.46) when compared with East Asians (M =1.33, sd =1.68) and Asian Americans (M = 0.70, sd = 0.29). In contrast, when after navigated with a printed map, East Asians committed fewer route recall errors (M = 0.13, sd = 0.35) than European Americans (M = 0.18, sd = 0.39) and Asian Americans (M = 0.18, sd = 0.41).

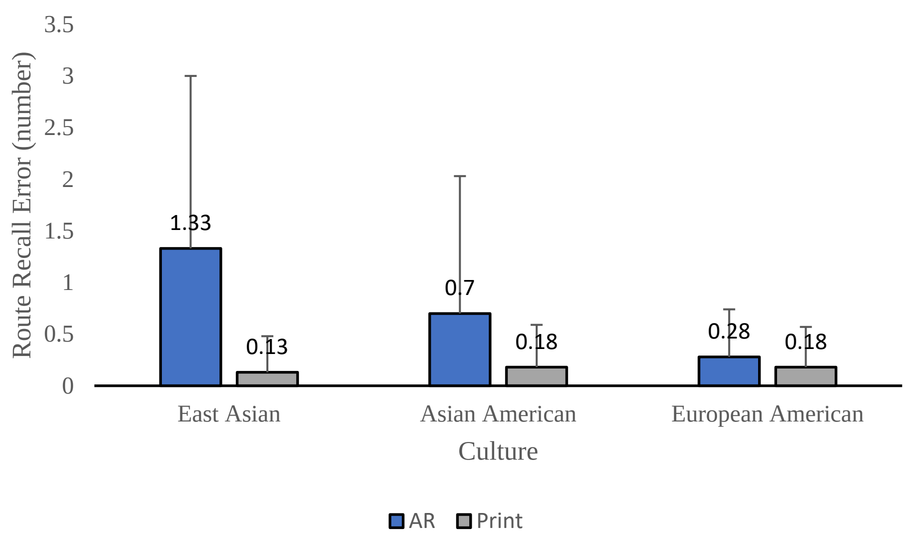

Figure 9. Navigation aid Type and Culture Effect on Route Recall Error

In order to test Hypothesis 3, a generalized linear mixed model was assessed for each outcome variable (perceived helpfulness on navigation task and perceived helpfulness on route recall task). The mixed model contains the random effects of subjects in addition to the usual fixed effects of cognitive processing styles interacting with the navigation aid type. It was important to assess the random effects because everyone's rating the subjective scales (perceived helpfulness and user experience) is different; some participants are more liberal with rating the subjective scales (generally higher scores) than others who may be more stringent with rating (generally lower scores). Thus, random effects model assumess that there is a hierarchical difference between the populations. This explains that some of the high ratings come from the same person who may be an overall high rating person. Since Hypothesis 3 examines the interaction between the cognitive processing styles and the navigation aid type, we only report the significance of the interaction, not the main effects of each predictor variable.

The results showed that there was no interaction between any of the cognitive processing styles and the navigation aid type on perceived helpfulness on navigation task. However, there was an interaction between the global thinking styles and the navigation aid type on perceived helpfulness on route recall task, as indicated in Table 3-6. This means that as global thinking tendency increases, a printed map was perceived more helpful in route recall task than an AR enabled navigation aid, supporting Hypothesis 3-5.

Table 3-5
Type III Tests of Fixed Effects on Perceived Helpfulness on Route Recall Task

Interaction	Numerator df	Denominator df	F	Sig.
Navigation Strategy*Navigation aid Type	1	55	.026	.871
Object Imagery*Navigation aid Type	1	40.028	1.002	.323
Spatial Imagery*Navigation aid Type	1	41	3.215	.080
Global Thinking*Navigation aid Type	1	39.217	5.494	**.024***
AHS*Navigation aid Type	1	39.600	.723	.400

***p<.001, **p<.01,*p<.05

Repeatedly, a generalized linear model was used to test Hypothesis 4. This hypothesis predicted that (1) there will be an interaction between global thinking style by navigation aid type on UX Efficiency, (2) there will be an interaction between Analysis-Holism Scale by navigation aid type on UX Novelty, (3) there will be an interaction between Spatial Imagery by navigation aid type on UX Perspicuity, and lastly (4) there will be an interaction between Object Imagery by navigation aid type on UX Attractiveness. The results showed that there were no statistically significant interactions among these predictor variables on the outcome variables.

CHAPTER 4

DISCUSSION

Findings

The objective of this study was to explore the effect of AR-enabled navigation aid on navigation performance in comparison with a printed map. In understanding the relationship, culture was considered as a moderating factor to better understand whether AR-enabled navigation aid would be more effective for a certain cultural group than the other. In addition, the study examined whether individual cognitive processing styles have an influence on perceived helpfulness and user experience differed by the navigation aid type.

This study confirmed the potential benefit of AR for navigation. The findings showed that navigation performance was significantly better when using the AR-enabled navigation aid than the printed map. Participants required shorter navigation time and committed fewer errors with AR-enabled navigation aid for at least two contributing factors. First, AR-enabled navigation aid showed and constantly updated directional cues until getting to the destination; in effect, participants can easily follow the cues without thinking where to go next. On the printed map, however, participants themselves had to interpret the route taken and where to take turns. In the obvious sense, route following is less time consuming than reading a map. Secondly, when participants navigated with printed map, they often stopped walking at the intersections and switched attention from map to the surrounding. When navigating with AR-enabled navigation aid, they did not need all these actions. They simply continued walking, and the virtual directional cues were updated corresponding to their walking speed. Therefore, overall navigation time was shorter with AR-enabled navigation aid than with printed map.

In analyzing route recall time and error, culture played a key role. Participants, self-identified as East Asians, required shorter route recall time after navigated with printed map than did European Americans. In addition, East Asians committed fewer errors than European Americans after navigated with printed map. European Americans, in contrast, required shorter route recall time and committed fewer errors after navigated with AR-enabled navigation aid than did East Asians. Therefore, it supported the second hypothesis that the effect of navigation aid type on route recall time and error were different by culture. Chua et al. (2005) reported that East Asians tend to fixate their eye movements on the background and surrounding environment, whereas European Americans tend to fixate more on the focal objects. In terms of design of the navigation aids used in this study, AR-enabled navigation aid provides object-oriented cues (i.e. landmark icons, directional arrows displayed on the floor). European American may have found the object-oriented cues more helpful when recalling the travelled routes due to their object focus tendency. On the contrary, printed map shows a holistic view of a space and provides more information about the surrounding. East Asians may have found this design more helpful when recalling the travelled routes due to their spatial imagery or global thinking tendency.

In addition, the result showed that the average number of both navigation and route recall errors was one or less. Although the numeric value was so small, it was still worth noting because one error can increase navigation or route recall time significantly. When participants made mistakes (i.e., taking wrong turns), it took them at least 10 – 20 seconds to get back to the correct path. If this was in emergency or time-sensitive situations, such as in hospitals or evacuation, the delayed navigation or route recall time might put people in danger.

The current study did not find statistically significant relationship between individual difference in cognitive processing styles and perceived helpfulness on navigation and route recall tasks. However, there was a tendency that participants with higher global thinking style—giving more attention to the whole rather than parts—found the printed map more helpful in recalling the travelled routes than the AR-enabled navigation aid. This may be because the printed map captures a holistic view of the space and provides information about the surroundings so that participants can easily make connection between the environment and themselves.

Limitations

The primary limitations of the current study were small size, homogeneous sample and unequal number of participants between the cultural groups. Among the fifty participants, there were only fifteen East Asians, eleven Asian Americans, and eighteen European Americans. The unbalanced number of participants for each cultural group was mainly because university's participant recruiting system could not control other cultural groups signing up for the study.

Another limitation was that East Asian participants recruited for this study were college students studying in the United States. Due to their extensive length of stay in the U.S., they might have learned or adopted the way American students perceive elements. As such, the Asian participants might not have been a typical representation of the East Asian group. If the study had recruited East Asian participants from an Asian country, the results could have been more accurate.

Moreover, this study did not take into consideration of participant's prior experience with the experimental space. Since the experiment took place in one of the main campus libraries, some participants might have already been more familiar with the space than others. It is possible that familiarity with the experimental space may influence participant's navigation performance.

Lastly, there were missing responses of individual cognitive processing styles survey (Appendix D) because some participants did not complete it before the deadline. In future study, surveys should be provided prior to the experiment, rather than one week after, so that administrator can track and better coordinate the responses.

Contributions & Directions for Future Study

Despite the limitations discussed above, the current research provides critical insights to both researchers and practitioners interested in AR technology for navigation. The findings demonstrated that AR significantly improved navigation performance when compared with printed map. But spatial memory was differed by cultural background or individual's cognitive processing styles. When designing a new type of navigation aid (such as AR-enabled navigation aid), these differences should be carefully dealt. Understanding individual differences will not only enhance design of a navigation aid but also mitigate varying levels of spatial ability.

Furthermore, AR-enabled navigation aid can be implemented on different display media such as optical head-mounted or projection displays. One concern with the hand-held optical see-through is that people tend to stare at the mobile screen too much without switching attention to the real environment. The unpaid attention to the surrounding can lead to safety issues. Optical head-mounted displays or spatial AR, i.e., projection mapping, may reduce these attention-switching issues in the future.

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APPENDIX A

CONSENT FORM

We are asking you to participate in a research study. In this form, you will find all the necessary information about the study. If you have any further questions, please ask to the researcher in charge.

Project Title: The role of Augmented Reality on spatio-temporal decision making and user experience in the context of indoor navigation.
Principal Investigator: Serena Seohyon Lee; Design & Environmental Analysis
Email: sl2357@cornell.edu **Phone**: (607) 697-3665

What the study is about
The purpose of this research is to introduce a new Augmented Reality Map for indoor navigation and examine how it affects people's wayfinding behaviors and user experience when navigating a complex building.

What we will ask you to do
In this session, you will be asked to find a location on the 4th floor of Mann Library on Cornell Campus. During the navigation, you will be given either a printed map or an AR-enabled navigation aid. Upon the completion of each task, you will fill out a post-survey which asks your experience and satisfaction. You are expected to use caution while navigating with the phone inside the building, and be aware of your immediate surroundings.

Risks and discomforts
We do not anticipate risks beyond those encountered in day-to-day life and daily cell phone use. However, there is always some very slight risk associated with looking at a cell phone while walking.

Benefits/Payments
There are no direct benefits to participant but you will earn 1 SONA Credit or $5 gift card upon completion of the study.

Photographs Recording
When participating in this study, you are expected to be photographed during the study. However, photo recording is optional. You can agree or disagree to be identifiable on photographs. If you decide not to be recorded, you can still participate in the study but a member from the research team will be taking notes of your session. These recordings will only be accessible to the investigators and we will not use the photos taken, or any other information you provide, for any other purpose.

[ ] I agree to be identifiable on the photographs.

[ ] I do not agree to be identifiable on the photographs.

Your name (Please print): ________________________________Date __________________

Your Signature ____________________________________ Date _________________________

Privacy/Confidentiality
We anticipate that the photos of your participation and the results of your questionnaire will be private and used only for the purpose of the study. Only the team of researchers will have access to this material. Once the study is completed all the files will be saved indefinitely on the personal hard-drive of the researchers.

Each researcher will add a personal security code to access at the files on the personal hard-drive.

Do you allow the researcher to add a picture of you conducting the study in scientific publications?
Yes [ ] No [ ]

Do you allow the researcher to add pictures of you in others media (newspapers, journals or public events), in order to show up the results of research and methodology? Yes [ ] No [ ]

Taking part is voluntary
Your participation is voluntary. You may refuse to participate before the study begins, discontinue at any time, or skip any questions/procedures that may make you feel uncomfortable.

If you have questions
The main researcher conducting this study is Serena Seohyon Lee, a MSc Student at Cornell University. Please ask any questions you have now. If you have questions later, you may contact Serena Seohyon Lee at sl2357@cornell.edu or at 607-697-3665. If you have any questions or concerns regarding your rights as a subject in this study, you may contact the Institutional Review Board (IRB) for Human Participants at 607-255-5138 or access their website at http://www.irb.cornell.edu. You may also report your concerns or complaints anonymously through Ethics point online at www.hotline.cornell.edu or by calling toll free at 1-866-293-3077. Ethics point is an independent organization that serves as a liaison between the University and the person bringing the complaint so that anonymity can be ensured. You will be given a copy of this form to keep for your records.

Statement of Consent
I have read the above information, and have received answers to any questions I asked. I consent to take part in the study.

Your Signature________________________________ Date____________________________________

Your Name (printed)____

Signature of person obtaining consent Date____

Printed name of person obtaining consent____

This consent form will be kept by the researcher for at least five years beyond the end of the study.

APPENDIX B

PRE-TASK QUESTIONNAIRE

1. Your participant ID given by the researcher:

   ____

2. What is your gender?

   ___ Male

   ___ Female

   ___ Prefer not to indicate

3. What is your age?

   ____

4. What is your ethnic background?

   ___ American Indian

   ___ Asian

   ___ Asian American

   ___ African American

   ___ Hispanic or Latino

   ___ White (Origins in Europe, the Middle East, or North America)

   ___ Native Hawaiian or Other Pacific Islander

5. How much do you reply on a printed map when navigating a space?

   ___ A great deal

   ___ A lot a

   ___ A moderate amount

   ___ A little

   ___ None at all

6. How much do you rely on a digital map (which shows real-time location positioning signal) when navigating a space?

___ A great deal

___ A lot a

___ A moderate amount

___ A little

___ None at all

APPENDIX C

POST-TASK QUESTIONNAIRE

1. Which map were you provided for this task?

○ AR Map (1)

○ Printed Map (2)

Display This Question:

If Which map were you provided for this task? = AR Map

2. What places or rooms did you see en route to your destination when using the AR map? Please try to list as many as possible.

____

____

____

Start of Block: Task Confusion & Clarity of hallway layout (Lawton, Charleston, Zieles, 1996)

3. I had no real plan in my mind for how to get back to the starting point when asked to find the way back.

○ Strongly disagree (1)

○ Somewhat disagree (2)

○ Neither agree nor disagree (3)

○ Somewhat agree (4)

○ Strongly agree (5)

4. I was able to maintain a sense of where the starting point was no matter where I was in the hallways.

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

5. I found myself hesitating at turning points in the hallways when trying to find my way back to the starting point.

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

6. I found the hallyways to be arranged in a clear and obvious pattern.

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

7. I found the arrangement of hallways on this floor to be confusing.

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

8. I was able to visualize the layout of the hallways in my mind as I was finding my way back to the starting point.

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

End of Block: Task Confusion & Clarity of hallway layout (Lawton, Charleston, Zieles, 1996)

Start of Block: User Experience Questionnaire

9. Please check a number following each statement on a scale from 1 to 7, indicating which best reflects your experience with the provided map.

	1	2	3	4	5	6	7	

Annoying (1)								Enjoyable
Creative (2)								Dull
Easy to learn (3)								Difficult to learn
Boring (4)								Exciting
Fast (5)								Slow
Inventive (6)								Conventional
Obstructive (7)								Supportive
Good (8)								Bad
Complicated (9)								Easy
Unlikable (10)								Pleasing
Usual (11)								Leading Edge
Unpleasant (12)								Pleasant
Motivating (13)								Demotivating
Inefficient (14)								Efficient
Clear (15)								Confusing
Impractical (16)								Practical

Organized (17)	○	○	○	○	○	○	○	Cluttered
Attractive (18)	○	○	○	○	○	○	○	Unattractive
Friendly (19)	○	○	○	○	○	○	○	Unfriendly
Conservative (20)	○	○	○	○	○	○	○	Innovative

End of Block: User Experience Questionnaire

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10. How much did you find each map **helpful for finding** your ways? Please rate on the slide bar below.

AR Map (1)	
Printed Map (2)	

11. How much did you find each map **helpful for recalling** the routes you traveled? Please rate on the slide bar below.

AR Map (1)	
Printed Map (2)	

12. How much did you pay attention to the surroundings in the real environment when using each map?

AR Map (1)	
Printed Map (2)	

APPENDIX D

INDIVIDUAL COGNITIVE PROCESSING STYLE SURVEY

Please indicate or click a number that suits best with your opinion.

Strongly Disagree	Disagree	Somewhat Disagree	Neither agree nor disagree	Somewhat Agree	Agree	Strongly Agree
1	2	3	4	5	6	7

Start of Block: Global Thinking

1. I like situations or tasks in which I am not concerned with details.

2. In doing a task, I like to see how what I do fits into the general picture.

3. In talking or writing down ideas, I like to show the scope and context of my ideas, that is, the general picture.

4. I like situations where I can focus on general issues, rather than on specifics.

5. I care more about the general effect than about the details of a task I have to do.

6. I like working on projects that deal with general issues and not gritty details.

7. I tend to emphasize the general aspect of issues or the overall effect of a project.

8. I tend to pay little attention to details.

End of Block: Global Thinking

Start of Block: Local Thinking

9. I like problems where I need to pay attention to details.

10. I like to memorize facts and bits of information without any particular context.

11. I tend to break down a problem into many smaller ones that I can solve, without looking at the problem as a whole.

12. I pay more attention to parts of a task than to its overall effect or significance.

13. In discussing or writing on a topic, I think the details and facts are more important than the overall picture.

14. I like to collect detailed or specific information for projects I work on.

15. I prefer tasks dealing with a single concrete problem, rather than general or multiple ones.

16. I prefer to deal with specific problems, rather than general questions.

End of Block: Local Thinking

Start of Block: OSIQ

17. I have photographic memory.

18. I can close my eyes and easily picture a scene that I have experienced.

19. My visual images are in my head all the time. They are just right there.

20. When reading fiction, I usually form a clear and detailed mental picture of a scene or room that has been described.

21. When I imagine the face of a friend, I have a perfectly clear and bright image.

22. I can easily remember a great deal of visual details that someone else might never notice. For example, I would just automatically take some things in, like what color is a shirt someone wears or what color is a shirt someone wears or what color are his/her shoes.

23. My images are very vivid and photographic.

24. I remember everything visually. I can recount what people wore to a dinner and I can talk about they way they sat and the way they looked probably in more detail than I would discuss what they said.

25. I prefer schematic diagrams and sketches when reading a textbook instead of colorful and pictorial illustrations.

26. I was very good in 3-D geometry as a student.

27. I have excellent abilities in technical graphics.

28. Architecture interests me more than painting.

29. When thinking about an abstract concept (e.g., 'a building'), I imagine an abstract schematic building in my mind or its blueprint rather than a specific concrete building.

30. My images are more like schematic representations for things events rather than like detailed pictures.

31. I can easily sketch a blueprint for a building that I am familiar with.

32. In school, I had no problems with geometry.

End of Block: OSIQ

Start of Block: Analysis-Holism Scale

33. Everything in the universe is somehow related to each other.

34. Nothing is unrelated

35. Everything in the world is intertwined in a causal relationship.

36. Even a small change in any element of the universe can lead to significant alterations in other elements.

37. Any phenomenon has numerous numbers of causes, although some of the causes are not known.

38. Any phenomenon entails a numerous number of consequences, although some of them may not be known.

39. It is more desirable to take the middle ground than go to extremes.

40. When disagreement exists among people, they should search for ways to compromise and embrace everyone's opinions.

41. It is more important to find a point of compromise than to debate who is right/wrong, when one's opinions conflict with other's opinions.

42. It is desirable to be in harmony, rather than in discord, with others of different opinions than one's own.

43. Choosing a middle ground in an argument should be avoided.

44. We should avoid going to extremes.

45. Every phenomenon in the world moves in predictable directions.

46. A person who is currently living a successful life will continue to stay successful.

47. An individual who is currently honest will stay honest in the future.

48. If an event is moving toward a certain direction, it will continue to move toward that direction.

49. Current situations can change at any time.

50. Future events are predictable based on present situations.

51. The whole, rather than its parts, should be considered in order to understand a phenomenon.

52. It is more important to pay attention to the whole than its parts.

53. The whole is greater than the sum of its parts.

54. It is more important to pay attention to the whole context rather than the details.

55. It is not possible to understand the parts without considering the whole picture.

56. We should consider the situation a person is faced with, as well as his/her personality, in order to understand one's behavior.

End of Block: Analysis-Holism Scale

Start of Block: Individual Navigation Strategy

57. I always keep in mind which direction I am moving (e.g. North, South, East, or West).

58. I do not think of my location in a building or complex in terms of North, South, East, and West.

59. It takes me a lot of mental effort to figure out my facing direction.

60. Labeled room numbers identifying parts of the building are very helpful in finding my way.

61. I find maps of a building, with an arrow pointing to my present location, to be very helpful.

62. I make a mental note of the number of streets or landmarks I pass on different sections of a path of travel.

End of Block: Individual Navigation Strategy
